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1218544

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(54) TEMPERATURE CONTROL SYSTEMS

(71) We, MULLARD LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2. a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

THIS INVENTION relates to systems for controlling the temperature of a charge of material movable within a furnace.

In processes involving the heat treatment of material it is sometimes necessary to move the charge of material within the furnace with a first region of the charge movable relative to a fixed temperature point or a given temperature profile in a first zone of the furnace and a second region of the charge being maintained at a fixed temperature in a second zone of the furnace. The relative movement between the charge and the furnace may be achieved either by maintaining the charge in a fixed position and moving the two-zone furnace system or by maintaining the two-zone furnace system in a fixed position and moving the charge.

Since the fixed temperature point or given temperature profile in the first zone may be at a different temperature from that of the fixed temperature at which the second region of the charge is maintained in the second zone, there will exist a temperature gradient between the zones, which gradient will change in magnitude as the distance between the fixed and moving controlled points changes. Such a changing temperature gradient may cause difficulty in maintaining one of the fixed temperatures at a desired value, even when means of controlling these temperatures well known in the art are employed.

According to the invention there is provided a system for controlling the temperature of a charge of material movable within a furnace, a first region of the charge being movable relative to a fixed temperature point or a given temperature profile in a first zone of the furnace and a second region of the charge being maintained at a fixed temperature in a second zone of the furnace, said system comprising first heating means associated with the first zone, second heating means associated with the second zone and including a power supply system, driving means for effecting the relative movement between the charge and the furnace, and control means in the power supply system which are coupled with the driving means for varying the power available to said second heating means according to the position of said second region of the charge within the second zone.

The control means may be coupled with the driving means to alter the power available to the second heating means either as a linear function of the distance between a controlled temperature point in the first zone of the furnace and a controlled temperature point in the second zone of the furnace or as a non-linear function of said distance.

The control means may comprise a variable auto-transformer which is mechanically coupled with the driving means. The driving means may comprise a wire or cable linked to the movable furnace or movable charge, the mechanical coupling being provided by the wire or cable passing over a cylindrical pulley or drum attached to a spindle of the variable auto-transformer. The output from the variable auto-transformer may either be applied directly to a system controlling the temperature of the second zone of the furnace or may be fed via a system of transformers. The E.M.F. applied to the system for controlling the temperature of the second zone may be expressed in the form $E=A+Bx$ where x is a linear function of the relative motion of the two controlled points. If the output of the mechanically driven variable auto-transformer is applied directly to the controlling system, the magnitude of A can be controlled only by setting the initial position of the auto-transformer at which movement commences and that of B by varying the diameter of the pulley or drum over which the wire or cable passes. By replacing the cylindrical pulley or drum on

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the auto-transformer with shaped cams of non-circular section any desired relationship between E and x can be obtained.

A third zone may be present in the furnace to thermally isolate the first and second zones. This third zone, situated between the first and second zones, is desirable when the controlled temperature in the first and second zones have a large difference.

An embodiment of the invention will now be described, by way of example, with reference to the diagrammatic drawings accompanying the Provisional Specification in which:

Figure 1 shows in schematic form a two zone traversing furnace comprising a temperature control system according to the invention;

Figure 2 shows the temperature distribution within the furnace of Figure 1 at one particular position of a charge within the furnace; and

Figures 3 and 4 show two preferred forms of a circuit suitable for use in the temperature control system associated with the furnace shown in Figure 1.

The two-zone traversing furnace shown in Figure 1 is of tubular form and comprises a first zone 1, hereinafter referred to as the hot zone, and a second zone 2, hereinafter referred to as the cool zone. The zones 1 and 2 have independent power supply systems. A carrier tube 3 is situated along the axis of the furnace and is secured to a movable carriage 4 by clamping members 5 and 6. The carriage 4 is free to move along guide rails and is moved in the direction indicated by the arrow 7 by a driving mechanism (not shown) connected to a wire linkage 8 at one end of the carriage. A wire 9 attached to the other end of the carriage is attached to a cylindrical drum 11 on a variable auto-transformer. This auto-transformer forms part of the temperature control system associated with the power supply system for the cool zone 2 of the furnace. A thermocouple 12 is present in the carrier tube 3 and this is electrically connected to the temperature control system associated with the power supply system for the cool zone 2. The thermocouple is adapted for movement with the carrier tube 3. A thermocouple 13 is present in the hot zone 1 and this thermocouple is electrically connected to a separate temperature control system associated with ith power supply system for the hot zone 1 of the furnace.

The operation of the furnace and temperature control system will now be described in connection with the growth of a single crystal body of gallium arsenide. In order to grow single crystal gallium arsenide it is necessary to slowly pass a charge of gallium arsenide through a freezing isothermal region of 1238°C whilst maintaining a suitable arsenic vapour pressure over the gallium arsenide. A sealed ampoule 14 of 70 cm length and 3 cm diameter is placed in the carrier tube 3 in the furnace. The ampoule 14 contains a charge of gallium arsenide 15 at the end present in the hot-zone 1 and a charge of arsenic 16 at the end present in the cool zone 2. The charge of gallium arsenide 15 is formed by the initial reaction of a quantity of gallium sealed in the ampoule with the arsenic. To grow device quality single crystal gallium arsenide it is necessary to maintain the charge of arsenic 16 at substantially constant temperature as the charge of gallium arsenide 15 is progressively moved through the freezing isothermal region. Figure 2 shows the temperature profile in the furnace in the shown position of the ampoule 14. The highest temperature in the hot zone 1 is 1,250°C and as the carriage is moved in the direction shown the gallium arsenide charge 15 in the ampoule 14 is progressively moved through this part of the hot zone 1 and then through the freezing isothermal region at 1,238°C. The temperature of the hot zone 1 is maintained constant by an independent temperature control system including the thermocouple 13 and associated with the power supply system for the zone 1. The arsenic in the cool zone must be maintained at 610°C. As the ampoule is moved through the furnace the temperature control system associated with the power supply system for the cool zone 2 changes the power supplied to the cool zone 2. This change in power may be fairly large and is achieved by the variable auto-transformer having the drum 11 to which the wire 10 is attached serving to decrease the off-set of the controller required to change the power input. Thus the power input to the cool zone 2 is progressively changed as the arsenic charge 16 in the sealed ampoule moves through the cool zone 2. With this temperature control system the change in arsenic temperature may be less than 2°C in the course of a 15 cm movement of the carrier tube 3 containing the ampoule 14.

In the circuits shown in Figures 3 and 4, which are similar in operation, the starting voltage "A" in the expression $E=A+Bx$ is set by auto-transformer V_A. The auto-transformer V_B adjusts the magnitude of factor "B". The auto-transformer V_C is driven by the furnace traversing mechanism, that is, by the wire 9 attached to the drum 11. The output voltage from V_A is then boosted proportionately to the distance of travel of the carriage 4 and carrier tube 3 by the addition of the output from V_C which is otherwise isolated from V_A by transformer T. The combined voltage of V_A and V_C is then applied to the load L constituted by the windings of the cool zone 2 of the furnace via temperature control system C which includes the thermocouple 12.

WHAT WE CLAIM IS:—

1. A system for controlling the temperature of a charge of material movable within a furnace, a first region of the charge being movable relative to a fixed temperature point or a given temperature profile in a first zone of the furnace and a second region of the charge being maintained at a fixed temperature in a second zone of the furnace, said system comprising first heating means associated with the first zone, second heating means associated with the second zone and including a power supply system, driving means for effecting the relative movement between the charge and the furnace, and control means in the power supply system which are coupled with the driving means for varying the power available to said second heating means according to the position of said second region of the charge within the second zone.

2. A system as claimed in Claim 1, wherein the control means are coupled with the driving means to alter the power available to the second heating means as a linear function of the distance between a controlled temperature point in the first zone of the furnace and a controlled temperature in the second zone of the furnace.

3. A system as claimed in Claim 1, wherein the control means are coupled with the driving means to alter the power available to the second heating means as a non-linear function of the distance between a controlled temperature point in the first zone of the furnace and a controlled temperature point in the second zone of the furnace.

4. A system as claimed in any of Claims 1 to 3, wherein the control means comprise a variable auto-transformer which is mechanically coupled with the driving means.

5. A system as claimed in Claim 4 where appendant to Claim 2, wherein the driving means comprise a wire or cable linked to the movable furnace or movable charge, the mechanical coupling between said driving means and the variable auto-transformer being provided by the wire or cable passing over a cylindrical pulley or drum attached to a spindle of the variable auto-transformer.

6. A system for controlling the temperature of a charge of material movable within a furnace substantially as herein described with reference to Figures 1 to 3 or Figures 1, 2 and 4 of the drawings accompanying the Provisional Specification.

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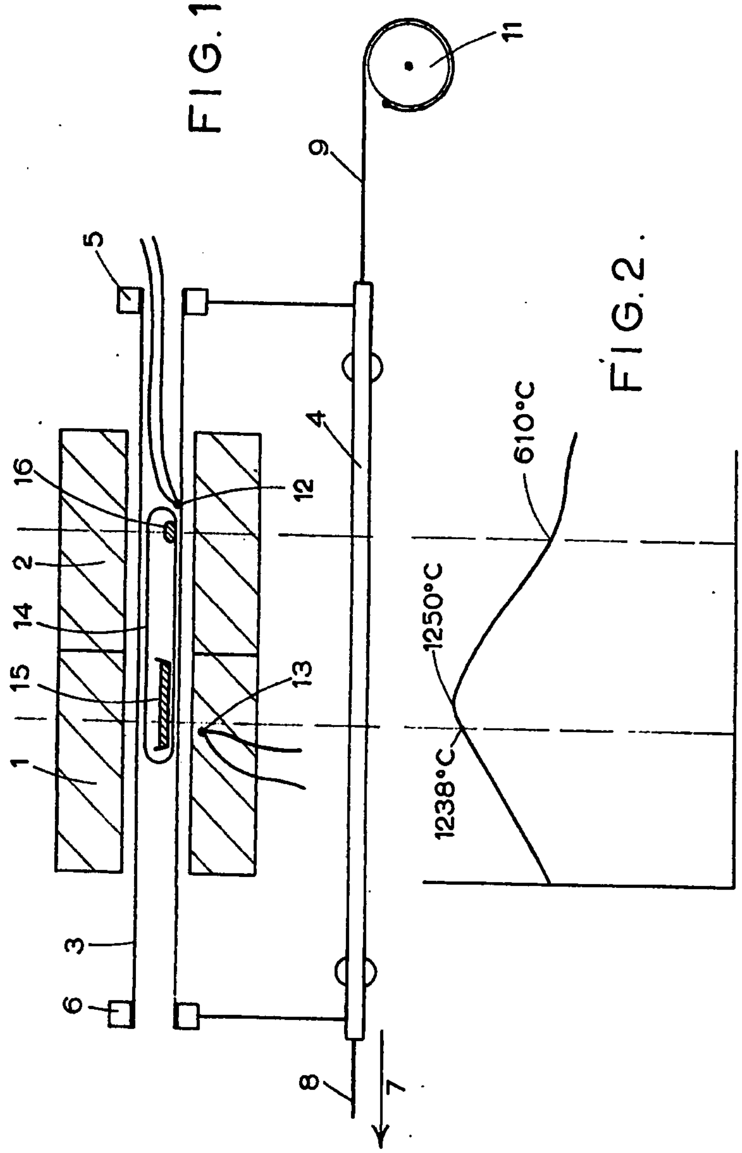

FIG.1.

FIG.2.

1218544 PROVISIONAL SPECIFICATION
2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 2

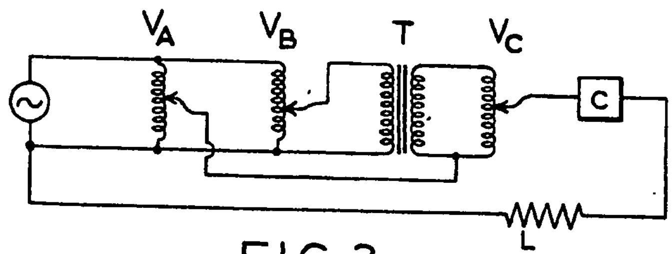

FIG. 3.

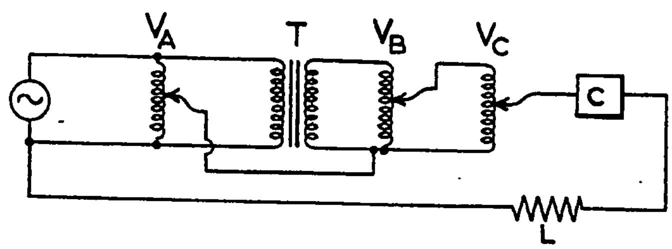

FIG. 4.